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Resource and Environmental Profile Analysis of Nine Beverage Container Alternatives. Volume I

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REPORT

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Environmental Protection Agency
Library Systems Branch, Room 2903
401 M Street, S.W.
Washington, D.C. 20460

DRAFT FINAL REPORT
February 6, 1974

MRI Project No. 3794-D

Volume I

For

Environmental Protection Agency
Office of Solid Waste Management Programs
Washington, D.C. 20460

Attn: Ms. Eileen Claussen
Resource Recovery Division

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by

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PREFACE

This report compares the total resource and environmental impact profiles for the manufacture and delivery of beverages. Nine basic beer and soft drink containers were evaluated. Six of these represent conventional container systems, whereas the other three are not presently employed widely. Various recycle and reuse options were analyzed.

Volume I is a summary and overview of the study results. In it is described the concept and methodology employed. This volume also contains the ranking of the container systems and the analysis of the findings.

Volume II is a detailed presentation of the basic data and calculations. Each system is presented as a series of systems and subsystems. Each datum used in this study is included in Volume II, along with a source citation.

The study was conducted under the general supervision of William E. Franklin, Manager of Resource and Environmental Economics Programs, who also served as an internal consultant. Project leader and principal analyst for the study was Robert G. Hunt. The computer analyst was Allen E. Woodall. Principal researchers were Richard O. Welch and James A. Cross. Assistance with the computer program was provided by Dan M. Epp and James E. Miller.

Approved:

MIDWEST RESEARCH INSTITUTE

Gary R. Nuss, Director
Economics and Management Science Division

February 6, 1974

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CHAPTER I

SUMMARY

Nine beverage container systems were compared to determine their relative total resource and environmental impact profiles. Impacts were determined in seven categories: virgin raw materials use, energy use, water use, industrial solid wastes, post-consumer solid wastes, air pollutant discharges and water pollutant discharges. These impacts were assessed for each manufacturing and transportation step in the life cycle of a container, beginning with extraction of the raw materials from the earth, continuing through the materials processing steps, product fabrication, use and final disposal.

The nine container systems encompass four basic material systems--glass, steel, aluminum and plastic. A fifth basic material is also included in packaging of the containers. This material is paper.

This study examines only the relative environmental effects for the seven categories listed. We have not included environmental categories which we judged to be redundant, or for which entirely inadequate quantitative data existed. These categories include such things as aesthetic blight, litter, waste heat and the like. It should also be understood that this is a relative comparison of beverage containers. No attempt is made to determine actual environmental damage arising from beverage container usage as compared to other product systems or to national or worldwide industrial totals.

Chapter II contains a disclosure of the basic assumptions used in this study. These assumptions are quite important and the reader is urged to examine them carefully. Other environmental studies are presently being made available for public scrutiny, and the basic assumptions of any two studies should be examined before comparisons between results are made. In addition, it should be noted that the results contained in this study pertain to comparative impacts of beverage containers only. Extrapolation of these results to other products will in most cases be invalid, even if the other products are made of the same materials. For example, the results contained in this study pertaining to glass and steel beverage containers cannot be applied directly to compare other products made from glass and steel because of differences in amounts of materials required, different material compositions and different manufacturing subsystems employed.

The nine container alternatives are given in Table 1. The product selected for study was beer containers. The primary reason that beer was selected rather than soft drink packages is that a 12-ounce package is standard for beer containers. This selection simplified the comparison of

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16. Abstracts

Nine beverage container systems were compared to determine their relative total resource and environmental impact profiles. Impacts were determined in seven categories: virgin raw materials use, energy use, water use, industrial solid wastes, post-consumer solid wastes, air pollutant discharges and water pollutant discharges. These impacts were assessed for each manufacturing and transportation step in the life cycle of a container, beginning with extraction of the raw materials from the earth, continuing through the materials processing steps, product fabrication, use and final disposal. The nine container systems encompass four basic material systems--glass, steel, aluminum and plastic. A fifth basic material is also included in packaging of the containers. This material is paper.

17. Key Words and Document Analysis. 17a. Descriptors

*Solid waste disposal,
*Environmental impacts,

Containers,
Aluminum,
Glass,
Steels,
Plastics,
Paper,
Cans,
Bottles,
Reclamation,
Raw materials,
Mining,
Manufacturing,
Economic analysis,
Process charting,
Energy consumption
Air pollution,
Water pollution,
Government policies.

17b. Identifiers/Open-Ended Terms

*Beverage containers,
Waste recycling,
Returnable containers.

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various container systems. However, environmental and resource profiles of soft drink containers were also made on a basis of impacts per 1,000 liters beverage delivered; although in the case of soft drinks, 16-ounce glass bottles were compared with 12-ounce cans and plastic bottles.

TABLE 1

NINE BEER CONTAINER ALTERNATIVES

	Code	Degree of Occurrence
Glass		
Returnable 19-trip on-premise	19-RET	Widespread
Returnable 10-trip off-premise	10-RET	Widespread
Returnable five-trip off-premise	5-RET	Regional
One-way conventional glass	OWG	Widespread
Plastic coated glass	PCG	Regional
Steel		
Conventional three-piece steel can--aluminum closure	CSTL	Widespread
All steel can	ALSTL	Nearly extinct
Aluminum		
Two-piece all-aluminum can	ALUM	Widespread
Plastic		
Plastic bottle[a/]	ABS	Test market

a/ The plastic resin was defined in terms of data available in the open literature. Impacts resulting from manufacture of proprietary plastics may be somewhat different.

Source: Midwest Research Institute

A. Ranking of Containers

The results of the resource and environmental profile analysis of beer containers are summarized in Table 2. The conventional containers clearly separate into two groups. The three glass returnable systems form a group with the lowest composite indices. Thus, using the assumptions and analysis procedures outlined in Chapter II, these containers are the ones which produce the least impact on natural resources and on the environment. The second group is OWG, CSTL and ALUM. These clearly are the containers that have the highest impact indices. From the point of view of this study,

these are the least desirable. However, rapid changes now taking place in the aluminum, steel and glass industries can cause changes in the relative rankings of these latter three, but these changes are not likely to give any of them a composite index lower than returnable systems.

TABLE 2

SUMMARY OF ENVIRONMENTAL PROFILE INDICES OF BEER CONTAINER ALTERNATIVES

	Composite Impact Index	19-RET Multiples
19-RET	32	1.0
10-RET	42	1.3
5-RET	87	2.7
ABS[a/]	108	3.4
ALSTL[a/]	116	3.6
PCG[a/]	118	3.7
OWG	126	3.9
CSTL	129	4.0
ALUM	143	4.5

a/ These containers are not presently used extensively as beer containers.

Source: Midwest Research Institute.

When compared to other conventional containers, the lead enjoyed by glass returnable systems is impressive. The 19-RET and 10-RET lead all other systems in five of the seven impact categories, while all these returnable systems lead all other conventional systems in the categories of energy, industrial solid wastes and air pollution. The reason for the favorable profile of these systems is that returnable systems require less material, thus bypassing much of the material processing and manufacture needed for one-way systems. Returnable systems do require more washing and transporting, but these do not overshadow the advantages of lower industrial processing per unit of beverage delivered to the ultimate consumer.

The three conventional "throwaway" systems considered are OWG, CSTL and ALUM. These systems as a group require significantly more natural resources and produce greater environmental effluents than the returnable systems. All members of this group are judged to be similar in their overall impact, although ALUM impacts are slightly greater. However, quite rapid

progress is being made in some areas of vital environmental concern for the aluminum, steel and glass industries. This progress may result in the aluminum container profile becoming comparable to that of the other one-way systems in the next few years, but it is unlikely that these changes will make ALUM (or the other two conventional one-way containers) comparable with the returnable systems.

Also included in this analysis were three containers which could be used for beer packaging but are not now widely used for that purpose. As shown in Table 2, all hypothetical or extinct containers have indices less favorable than 5-RET, but more favorable than conventional one-way systems. The most favorable of the three is ABS, but the differences between the three are not great. One attractive possibility is that the ABS system could potentially occur as a returnable system. Because the ABS one-way impacts are less than OWG impacts, the possibility exists that a returnable plastic bottle could have as low an index as a returnable glass bottle.

One other unconventional system is plastic coated glass (PCG). As a one-way system, it produces much more impact than returnable systems. Thus, as a one-way system it would not favorably replace a returnable glass system. However, a returnable PCG system might also be superior to present glass systems because less glass is required by the plastic coated glass than conventional returnable glass bottles.

B. Soft Drink Containers

Calculations were also carried out for soft drink containers delivering a "standard unit" of 1,000 liters of beverage. As shown in Table 3, the results are quite similar to those for beer containers. That is, the returnable glass system has a significantly lower impact index than the one-way systems. The aluminum system is last at this time, but as indicated for the beer containers, it is last by only a marginal amount.

An important aspect of the soft drink systems is the fact that a wide range of glass bottle sizes and weights are in common use. Thus, the impacts of the container system per 1,000 liters of beverage vary with the particular container used. In Table 3, a 16-ounce returnable bottle is compared with a 12-ounce one-way container because the most complete data were available for these sizes. However, calculations using a wide range of glass bottle configurations show that no matter which available container is chosen, the conclusions of this study are not altered.

TABLE 3

SUMMARY OF SOFT DRINK CONTAINER ALTERNATIVES

	Composite Impact Index	15-RET Multiples
15-RET	32	1.0
ABS[a/]	90	2.8
ALSTL[a/]	103	3.2
PCG[a/]	110	3.4
CSTL	115	3.6
OWG	125	3.9
ALUM	128	4.0

a/ These containers are not presently used extensively as soft drink containers, although PCG markets are rapidly expanding.

C. Recycle and Reuse

Considerable potential exists for improving the environmental profile of any container system through reuse and recycle. As has been shown in the primary results for containers presently in use, the reusable glass bottles possess considerable environmental advantage over the other conventional containers, even if only five trips are achieved per bottle. However, other possibilities of reuse or recycle exist for the one-trip containers.

An analysis of the weighted indices for various percentages of recycled materials shows that substantial improvements in the environmental profile are possible. Recycling materials at a 100 percent rate results in environmental profile improvement so great that plastic, aluminum, and all steel containers are better than most present widely used containers--even the glass returnable 5-RET. Environmental improvement also results from recycling glass one-way bottles, but the improvement is not as great.

It is possible that plastic or glass bottles can participate in both recycle and reuse. Plastic and glass can be readily recycled if clean scrap is available, so the advantages of recycling can be capitalized on. It is possible that a plastic returnable bottle will soon be viable. In that event, both reuse and recycle options will be available to both plastic and glass. A returnable bottle made from recycled material would have a highly favorable environmental impact profile compared to other beverage packaging options.

All of the material systems studied show index improvement as a result of recycling. The greatest improvement for any of the material systems as a result of recycling is for aluminum. The impact index drops from 143 at current recycling rates for aluminum to 26 for 100 percent recycled aluminum, a decrease of 82 percent. Steel and plastic show improvements of 64 and 60 percent for 100 percent recycling, while glass improves by only 6 percent.

At 100 percent recycling, steel, aluminum and plastic achieve impact indices comparable to the 19- and 10-trip glass returnables. However, this is an unrealistic recycling rate and could never be achieved on a widespread basis. Even at 50 percent recycling, none of the systems achieve better than a "tie" with 5-RET and have impact indices considerably greater than those of 10- and 19-trip returnable systems. However, 50 percent recycling of any of these materials on a regional or nationwide basis appears unlikely in the near future. Thus we conclude that recycling systems possess advantages over one-way systems, but are not superior to returnable systems.

Figures 3 and 4 presented in Chapter 4 show that at only 2 or 3 trips, glass and plastic returnable systems surpass any one-way system. At a trippage of ten, they have a lower index value than any system using up to 50 percent recycled material (a very high recycling rate). Thus, under present conditions and assumptions of this study, returnable systems seem to possess the lowest overall environmental impact unless quite high recycling rates are assumed for other container systems.

CHAPTER II

STUDY APPROACH AND METHODOLOGY

A. Introduction

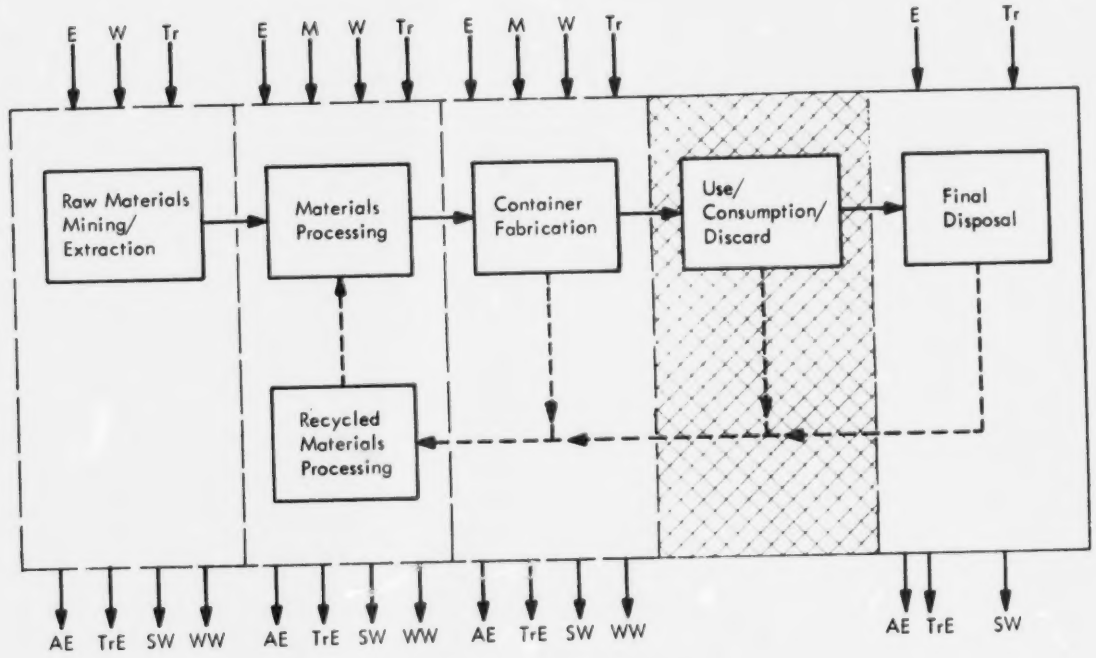
The purpose of an environmental impact profile study is to determine which of a number of competitive products produces the greatest and the least environmental degradation. Environmental degradation may take any or all of four forms: (1) aesthetic blight; (2) alteration of food chains; (3) creation of health hazards; (4) depletion of resources; or (5) degradation of the quality of air, water, and land. The seriousness of an impact depends on the extent of its participation in these forms of degradation.

It would be ideal if an objective quantitative analysis would reveal a given environmental impact's true amount of degradation. However, this is not the case. For example, a manufacturing plant may discharge "x" pounds of sulfur oxides to the air and "y" pounds of oil to a nearby river. But the precise extent to which these two pollutants contribute to environmental degradation cannot be readily determined (although there is general agreement that degradation has occurred). The point of view taken in this study is that even though the true environmental damage cannot be determined, it is useful to establish reliable estimates of the relative impact of competitive products. Thus, even if the true damage of energy use or air pollution is not known, we can conclude that a product responsible for more energy use or more air pollution produces more environmental degradation.

B. Basic Approach

The effort expended in the study went into determining quantifiable impacts of manufacture. The term "manufacture" is used throughout this report in a general sense--it includes those activities associated with materials from the time they are severed from the earth to the point where the finished container has been finally disposed of, including all transportation links in the processing sequence. The manufacturing activities which intervene are designated processes or subprocesses. A summary of the impacts documented is shown in Figure 1.

The nine container systems considered in this report are derived from four basic raw materials. These materials are: glass, plastic, steel, and aluminum. For each material system the manufacturing cycle was broken into its component processes and subprocesses for the purpose of identifying environmental impacts. For some systems this task is relatively simple and for some it is quite complex. For example, glass container manufacture



SUMMARY OF INPUT/OUTPUT CATEGORIES

INPUT	OUTPUT
E = Energy (in all forms)	AE = Atmospheric Emissions
M = Virgin Materials (consumed and unconsumed)	TrE = Transportation Effluents (for each fuel type)
W = Water	SW = Solid Wastes
Tr = Transportation to Next Operation (including all modes, all fuels in each mode)	WW = Waterborne Wastes

Figure 1 - Summary of Environmental Impacts for Container Manufacture

is divided into ten basic processes, with many of the processes not requiring more detailed analysis of subprocesses. At the other extreme is the ABS polymer which is manufactured by utilizing 15 basic processes. In several instances, a detailed analysis of several subprocesses was required. In one case (petroleum refining) it was necessary to determine completely the manufacturing parameters for seven such subprocesses.

For each process and subprocess, a set of seven basic impacts was determined:

1. Raw materials: The number of kilograms and type of virgin raw materials input to each operation were determined in terms of a given product output. Materials not intended to become part of the finished product, such as cooling water and fuels, were excluded from raw materials. Other raw materials, such as additives, which aggregate to less than 5 percent of the total weight of the finished container were included in this category by reporting their weight in the finished product. This provides an estimate of the virgin raw materials which should be allocated to materials which occur in small quantities.

2. Energy: The energy used by each operation, including transportation, for a given product output was reported. Process energy used by the actual manufacturing operations was considered. That used for space heating of buildings and other miscellaneous categories was excluded wherever possible. Energy content of certain organic raw materials was also included in energy summations. (See the discussion on page 12.) The second-order energy necessary to extract, process and transport fuels are included as well as the heat of combustion of the specific fuels used in a system. The energy value assigned to electricity use was the energy associated with the consumption of fuels necessary to deliver electricity to the customer (see Volume II, Chapter I, for more details).

3. Wastewater volume: The volume of water discharged per unit of product output from each operation was reported. An alternative measure of water is the actual volume consumed or removed from natural water cycles. However, such data are not available for every system. This impact category considers water use only, not what is discharged from a process into the water in the form of pollutants. (This factor is covered separately.)

4. Industrial solid wastes: The volume of solid waste per unit of product output which must be landfilled, or disposed of in some other way, was determined also. Three categories were measured: process losses, fuel combustion residues (ashes) and mining wastes. The first category--process discards--includes wastewater treatment sludges, solids resulting from air pollution control and trim and waste materials from manufacturing operations which are not recycled. Fuel combustion residues are ash generated by coal combustion. Mining wastes are primarily materials discarded due to raw ore processing and do not include overburden removed to expose ore.

5. Post-consumer solid wastes: The volume of solid wastes generated by disposing of the container and its associated packaging was determined. This is solid waste which most likely would be discarded into municipal solid waste streams. It was assumed that 9 percent would be incinerated and 91 percent would be landfilled. It was assumed that the amount of material recycled directly from municipal waste is at present less than 1 percent of the total volume.

6. Atmospheric emissions: This category includes only those emissions generally considered to be pollutants expressed in kilograms per unit of product output. Eleven identifiable pollutants were considered for each operation--particulates, nitrogen oxides, hydrocarbons, sulfur oxides, carbon monoxide, aldehydes, other organics, lead, odorous sulfur compounds, ammonia and hydrogen fluoride. The amounts reported represent actual discharges into the atmosphere after existing emission controls have been applied. All such atmospheric emissions were treated as being of equal weight, and no attempt was made to determine the relative environmental impacts of each of these pollutants. However, we do note that there are differences in the relative harm caused by air pollutants. There is not sufficient documentation available to weight them with respect to each other now.

7. Waterborne wastes: This category includes the water pollutants from each operation expressed in kilograms per unit product output. These are effluents after wastewater treatment has been applied and represent discharges into receiving waters. Thirteen specific pollutants are included--BOD, COD, suspended solids, dissolved solids (oil field brine), oil, fluorides, phenol, sulfides, acid, alkalinity, metal ions, chemicals and cyanide. Other factors such as turbidity and heat, were not included because acceptable data were not available.

C. Organic Raw Materials--Unique Considerations

A unique situation exists for products utilizing organic raw materials, such as wood, crude oil and natural gas. These materials have alternative uses as feedstocks for material goods such as paper or plastic products or as fuels for energy. In assessing resource depletion, then, use of organic materials can be considered as depleting either material resources or energy resources.

It is our opinion that viewing organic materials either as a material resource or as an energy resource is justifiable from an environmental point of view. In given sets of circumstances, either view may be desirable. In certain cases, calculations show that some plastic products not only require less process energy, but also use fewer energy resources (including energy content of basic physical materials) than some alternative materials.

Thus, situations exist where manufacture of plastic materials--even when using natural gas and petroleum as a material feedstock--conserves natural gas and petroleum as compared to competitive products.

The treatment given organic materials in a total environmental profile analysis must be considered carefully. There are basically two options available: (1) organic materials used as a material to be converted into a product may be considered as material resources; or (2) they may be considered as energy resources.

In the first case, the organic materials intended to become part of a finished product are simply measured in kilograms and treated as any mineral resource, with one exception. A unique consideration for organic materials is the inherent fuel value of the material. As natural gas and petroleum undergo chemical processing, losses in chemical potential energy occur. That is, a pound of petrochemical made from natural gas has less fuel value than a pound of natural gas. Thus, a loss in the fuel value of the material has occurred and should be counted as a loss to the world's energy reserve. (The energy loss is given up in chemical reactions when hydrocarbon feedstock is converted to a new compound.)

In the second case, organic materials are simply counted in terms of their energy content. The amounts of wood, natural gas, and petroleum severed from the land are measured in terms of joules of energy, rather than in kilograms. Thus, they are considered as energy resources.

Another point of consideration regarding the fuel value of organic materials is that finished products are a potential fuel even after they have been used and discarded. Thus, if the solid waste stream is incinerated and energy recovered, part of the original fuel value is reclaimed. However, this point is academic at present because, in actual fact, products are typically landfilled, burned in open dumps or incinerated with no heat recovery. Virtually no energy is recovered from solid waste streams, even though the potential does exist.[1/] In addition, the energy content of all products will never be available for recovery. Some portion of the products will become litter or will be discarded into waste streams too small for economic heat recovery operations. Even in the distant future, full recovery of the residual energy inherent in organic products will probably never be achieved.

Because of these considerations, a strong case can be made for counting plastic materials as an energy resource rather than as a material resource. This treatment reflects more accurately the primary environmental

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1/ We recognize that several resource recovery installations which recover energy from solid wastes exist today and that there is an emerging technology under development. However, at present the actual useful recovery of the residual energy content of organic wastes is negligible in comparison to the amount disposed.

concern of the plastics industry which is the consumption of energy reserves in the form of natural gas and petroleum. These fuels are at present, and in the near future will be, in short supply to a greater extent than any other major natural resource. As mentioned earlier, the material resources considered in this study such as limestone and iron ore are much more abundant than natural gas and petroleum. Counting petroleum and natural gas use as equivalent on a kilogram-for-kilogram basis with limestone would not give as true a resource use picture as counting the energy value of these materials. Because essentially no recovery of the intrinsic fuel value of finished plastic products is practiced at present, the impact on the nation's energy reserves due to plastics manufacture is the sum of the process energy required for plastics manufacture and the inherent fuel value of the organic materials consumed. Thus, treating organic materials as an energy input rather than as a physical quantity of material is a more accurate statement of environmental impact and places the comparison of competitive container systems on a more logical basis.

On the other hand, we have treated wood fiber both as a material resource and as an energy resource. On a worldwide basis, slightly less than half of the wood harvested is used as a fuel, with the remainder used as a material resource. Thus, wood serves for either use. It is difficult to judge the present and future aspects of wood fiber depletion because of its renewable character. If wood is viewed as a material resource, then projections for its future use indicate that adequate amounts of wood can be grown to maintain world reserves. On the other hand, if significant conversion from present fossil fuel use patterns to use of wood as a fuel takes place, the annual harvest of wood would exceed the annual growth and depletion would take place. Thus, it seems reasonable to classify wood used as a material resource with fossil materials such as sand and limestone for which adequate long-term supplies exist. On the other hand, it seems reasonable to classify wood harvested to be used as an energy source with hydrocarbon fuels for which long-term supplies are doubtful. Therefore, we have divided the pulpwood harvested for paper manufacture such that the portion which is intended for use in paper is measured in kilograms of fiber, and portion burned for energy is measured in joules.

D. Methodology

The general approach used to carry out the calculations for the quantitative comparison was straightforward. All processes and subprocesses were first considered to be separate, independent systems. For each system a standard unit such as 1,000 kilograms of output was used as a basis for calculations. A complete materials balance was first determined. If marketable co-products or by-products were produced, the materials inputs were adjusted to reflect only the input attributable to the output product of interest.

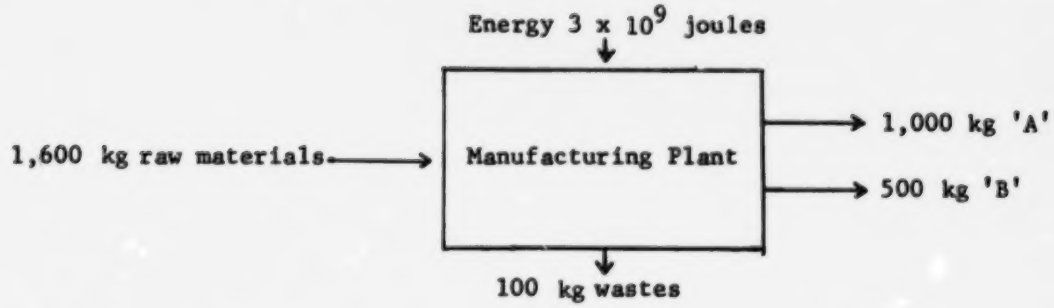
To illustrate this point, consider a hypothetical manufacturing process that produces 1,000 kilograms of product 'A' in which we are interested. At the same time, it produces 500 kilograms of co-product 'B' and 100 kilograms of waste in the form of air and water pollution, solid waste and wastewater. The total input of raw materials is 1,600 kilograms as shown in Figure 2. An energy input of 3×10^9 joules is assumed for this example. The output is 1,000 kilograms of product 'A' and 500 kilograms of product 'B.'

A 500-kilogram credit has been applied to the input materials because we are not interested in product 'B.' This reduces the input from 1,600 kilograms to 1,100 kilograms. In addition, because product 'B' is one-third of the product output of the process by weight, one-third of the wastes, or 33 kilograms, is attributed to product 'B'; a new waste figure of 67 kilograms (100 kilograms - 33 kilograms = 67 kilograms) results. Thus the raw material input value for product 'A' is 1,067 kilograms (1,100 kilograms - 33 kilograms = 1,067 kilograms).

Once the detailed impact information had been determined for 1,000 kilograms or 1 metric ton of output from each subprocess, a master flow chart was established for the manufacture of containers. Using known yield data, the pounds of output of each subprocess necessary to produce 1,000 kilograms or 1 metric ton of finished containers were determined. Summary tables of impacts for the manufacture of 1,000 kilograms or 1 metric ton of containers were then constructed. (Details of calculations, summary tables and data sources are included in Volume II.)

For purposes of comparing the nine container systems, another adjustment of the raw numbers was necessary. The purchase and consumption of containers (their ultimate utility) depends not on the number of kilograms of containers, but on the number of units. Hence, the raw values based on weight were converted so that containers may be considered on a unit-by-unit basis. A standard unit of 1,000 liters of beer delivered in 12-ounce containers to the customer was selected as the unit of comparison.

Up to this point, data gathering and calculations for each system were kept entirely independent of each other. After converting the data to a 1,000 liter basis, the nine systems were compared for the first time. The data in this form are the unweighted comparative data. Further refinement of the comparative analysis is possible by using a weighted index system that takes into account the relative importance of each environmental impact. This system of refinements is discussed in Chapter IV.



For analysis purposes, a new flow diagram would be established as shown here.

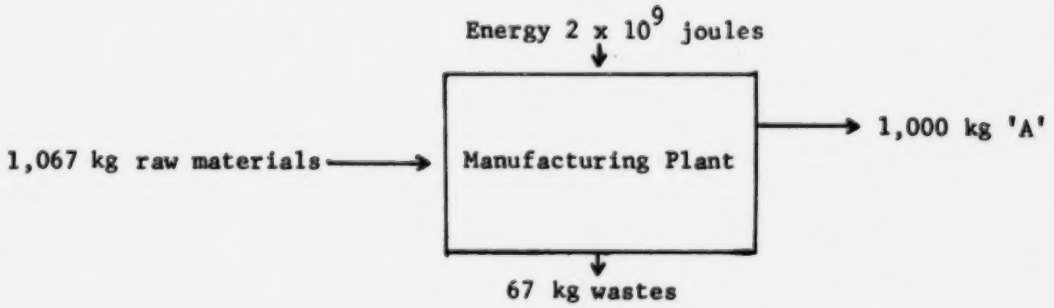


Figure 2 - Diagram Illustrating Co-Product Credits

E. Assumptions and Limitations

An important part of any study concerns the assumptions that must be made since some assumptions are always necessary to limit a study to reasonable scope. It is important for the reader to know what assumptions have been made in order for him to understand fully the scope and applicability of the study.

In the course of this research, the following assumptions and limitations were operative:

1. Data sources: An attempt was made in every case to obtain data which were "typical" and which could be verified in the open literature. Extensive use was made of government agencies and publications, technical associations and open literature sources. National average data were used where possible. Certain sets of data involved proprietary processes so that information was submitted to us on a confidential basis. However, data in the public domain were used whenever possible.

2. Geographic scope: The "environment" was defined as the environment of the USA. Impacts occurring outside this country were not considered. For example, iron ore mining wastes in Canada were not included.

3. Secondary impacts: Impacts resulting from extraction, processing and transporting fuels are called secondary impacts and were considered, as well as the primary impacts of the fuel combustion. Secondary impacts resulting from effects such as manufacturing the equipment used in container manufacture are small per unit output, and can be excluded without significant error.

4. Small amounts of materials: The impacts associated with materials which aggregate to less than 5 percent by weight of the container were not included. The list of materials which comprise the "less than 5 percent" category was examined to insure that no known "high environmental impact" materials were excluded from the analysis. This inspection insures that the values from this assumption do not lead to an error of greater than 5 percent in the final results.

5. Electricity: Electrical energy is considered from the point of view of its impact on the total energy resources of the nation. A national average energy expenditure of 12,400 Btu of fossil fuels and hydropower is required for each kilowatt-hour of electricity made available to the public. Hence, this conversion factor is used rather than the direct use conversion factor of 3,400 Btu per kilowatt-hour. The impacts from mining or extraction of these fuels were included in the analysis.

6. Impacts of scrap: Environmental impacts of scrap are considered to be only those impacts incurred after the scrap is discarded from the manufacturing site. Usually this includes only transportation and scrap processing steps. The environmental impacts of manufacture of material which subsequently becomes scrap is allocated to the prime product. For example, suppose an idealized metal fabrication plant requires 1.2 metric tons of steel to produce 1.0 metric tons of prime product and 0.2 metric tons of steel scrap. The impacts associated with the manufacture of 1.2 metric tons of steel are all allocated to the prime product with none being allocated to the scrap.

7. Point sources of pollution: The burden on specific ecosystems was not considered--i.e., at specific point sources or geographic locations. It was assumed the operations took effect on the environment everywhere, not just where manufacturing operations are located, for example.

8. Lack of detailed data: A basic hindrance to a study of this type is that many industrial plants do not keep records in sufficient detail to determine the data in the desired form. For instance, if pollution data are needed for a specific subprocess in a plant, that information may not be available. The plant may have data only for several combined processes. In this event, prorations must be made to the particular processes of interest. As the concept of total environmental impact studies gains acceptance, it is likely that more industries will make an effort to collect these types of data from their own operations and on a unit process basis. Engineering calculations of materials balances for subprocesses were used in some instances where actual operating data are not available.

9. Effluent data: Current actual conditions were assumed for air, water and solid waste discharges to the environment. We made no attempt to derive and apply effluent standards which may be in effect at some future date. However, the application of future standards has the effect of shifting effluents from one category into others. It does not add or subtract from total amounts of effluents. For example, air pollution control usually converts air pollution to water pollution and solid waste. Thus, reducing air pollution from a plant will usually increase its water pollution and/or solid waste discharge.

CHAPTER III

BEER CONTAINERS--THE ENVIRONMENTAL PROFILE

The comparative environmental impacts resulting from the manufacture, filling and delivery of nine container systems are discussed in this chapter. The impacts are presented in numerical form. A data summary is presented first, followed by an unweighted index evaluation which facilitates the comparison of the overall environmental profiles. A weighted index system is then introduced which places the various impact categories in perspective and makes the comparison of each system more meaningful.

A. Data Summary

The environmental profiles of the nine beer container systems were derived from a series of calculations and data analyses following the methodology outlined in the previous chapter. Hundreds of calculations were involved, leading in a stepwise manner, for each impact category for each process and subprocess. All of the detail and supporting calculations are contained in Volume II of this report. A description of each system and the abbreviations used in this report are in Table 4.

Table 5 displays the numerical summary of these calculations with the impacts reported in their appropriate units for the number of 12-ounce containers (2,817) which deliver 1,000 liters of beverage. Also included in parentheses are data for 1,000 gallons (10,700 containers). These totals result from the aggregation into each impact category of all values from each process and subprocess of each container system.

B. Ranking Procedures

In order to draw conclusions about the comparative environmental impact of these nine systems, it is necessary to develop a procedure to rank these systems. Table 6 contains the rank of the nine systems for each impact category, but fails to aid in an overall ranking of the nine systems. A survey of the numbers in Table 6 reveals that this ranking is not an easy task. There is no container system which either leads or lags in all impact categories, even though 19-RET leads in five of the seven categories. However, ALUM leads in two categories and is last in two categories, exemplifying the problems of ranking systems.

TABLE 4

BEER CONTAINER SYSTEMS DESCRIPTIONS

Abbreviation	Container Weight (kg)	Container Weight (Oz)	Description
19-RET	0.277	9.8	Glass 19-trip on-premise returnable bottle - steel closure - three-trip paper packaging
10-RET	0.277	9.8	Glass 10-trip off-premise returnable bottle - steel closure - three-trip paper packaging
5-RET	0.277	9.8	Five-trip off-premise returnable bottle - steel closure - one-trip paper packaging
ABS	0.035	1.2	ABS one-way plastic bottle - steel closure
ALSTL	0.054	1.9	Three-piece all steel can
PCG	0.159	5.6	Plastic coated one-way glass bottle - steel closure
OWG	0.186	6.6	One-way glass bottle - steel closure
CSTL	0.050	1.8	Conventional three-piece steel can - aluminum ring pull closure
ALUM	0.020	0.7	Two-piece all-aluminum can

Note: All bottle systems include paper packaging of empty and filled bottles. Paperboard six-pack carriers were included in all bottle systems except the 19-trip off-premise. All can systems include paper packaging of empty and filled cans. Plastic ring six-pack carriers were included.

Source: Midwest Research Institute.

TABLE 5

SUMMARY OF COMPOSITE DATA FOR CONTAINER SYSTEMS FOR 1,000 LITERS (AND 1,000 GALLONS) BEER

	19-RET	10-RET	5-RET	ABS	ALSTL	PCG	OWG	CSTL	ALUM
Raw Materials - kg (lb)	112.34 (937.07)	184.36 (1,537.82)	409.38 (3,414.74)	115.77 (965.72)	243.19[a] (2,028.52)	788.77 (6,579.28)	900.19 (7,515.34)	201.09[b] (1,677.36)	69.27[c] (577.79)
Energy - 10^9 joule (10^6 Btu)	4.83 (17.33)	6.59 (23.65)	13.00 (46.61)	20.34[d] (72.94)	11.49 (41.21)	18.92 (67.87)	20.15 (72.25)	15.99 (57.35)	25.33[e] (90.85)
Water - 10^3 liter (1,000 gal)	11.29 (11.29)	15.35 (15.35)	32.42 (32.42)	41.69 (41.69)	37.77 (37.77)	34.90 (34.90)	36.77 (36.77)	33.10 (33.10)	16.48 (16.48)
Industrial solid waste - cu m (cu ft)	0.04 (5.47)	0.05 (7.79)	0.10 (13.84)	0.04 (6.39)	0.53 (71.10)	0.21 (28.67)	0.24 (32.42)	0.45 (61.36)	0.21 (28.77)
Atmospheric emissions - kg (lb)	9.85 (82.22)	13.34 (111.29)	28.02 (233.78)	36.67 (305.95)	18.87 (157.41)	36.79 (306.80)	39.37 (328.46)	28.04 (233.96)	45.64 (380.73)
Waterborne wastes - kg (lb)	4.50 (37.60)	5.38 (44.88)	9.50 (79.24)	9.51 (79.34)	41.82 (348.83)	7.74 (64.57)	8.00 (66.74)	40.20 (335.34)	29.88 (249.31)
Post-consumer solid wastes - cu m (cu ft)	0.05 (7.16)	0.09 (11.94)	0.21 (28.86)	0.20 (27.03)	0.02 (3.48)	0.27 (37.13)	0.30 (40.94)	0.02 (3.21)	0.02 (3.17)

a/ An additional 82.9 kg of iron ore are imported.
b/ An additional 61.2 kg of iron ore and 65.2 kg of bauxite are imported.
c/ An additional 221 kg of bauxite are imported.
d/ This includes 5.7×10^9 joules of energy equivalent of petroleum and natural gas used as a material resource.
e/ This includes 2.5×10^9 joules of energy equivalent of petroleum and natural gas used as a material resource (mostly petroleum coke).

Source: Midwest Research Institute.

TABLE 6

RANK OF SYSTEMS FOR EACH IMPACT CATEGORY[a/]

Impact Category	19-RET	10-RET	5-RET	ABS	ALSTL	PCG	OWG	CSTL	ALUM
Raw materials	2	4	7	3	6	8	9	5	1
Energy	1	2	4	8	3	6	7	5	9
Water	1	2	4	9	8	6	7	5	3
Industrial solid wastes	1	3	4	2	9	5	7	8	6
Atmospheric emissions	1	2	4	6	3	7	8	5	9
Waterborne wastes	1	2	5	6	9	3	4	8	7
Post-consumer solid wastes	4	5	7	6	3	8	9	2	1

a/ Lowest value of resource use or effluent is ranked "1", etc.
Source: Midwest Research Institute.

We have used a scheme that allows an overall index of environmental impact to be derived for each system. In order to do this, an indexing scheme must be derived which first converts the numbers of Table 5 into dimensionless ratios so that impacts measured in different units (i.e., joules and kilograms) can be directly compared. Furthermore, the indexing scheme must convey information not only about which system leads or lags in a given category, but by how much it leads or lags other systems.

C. Index of Environmental Impacts

Table 7 is a set of dimensionless index values which satisfies the requirements set forth above. Each index value is the ratio of each impact value in Table 5 to a standard value, multiplied by 100. The standard values were chosen to be the sum across Table 5 for each impact category divided by nine. Thus, the standard value is the average impact value for each category. (The reader is referred to Volume II for more details of how the index values are calculated.) These dimensionless indices may be summed for each container system to obtain an overall index of environmental impact (Table 8).

Some caution needs to be exercised in using index schemes in this manner. The possible theoretical errors are discussed in Volume II. However, extensive computer analysis and investigation of these possible problems in relation to Table 7 lead us to conclude that Table 7 is valid.

D. Weighted Index

Unweighted index values may be misleading as to the true relative rank of the container system. A survey of the index numbers in Table 7 reveals that the largest number is a value assigned to raw materials for glass containers. The implication is that this value represents the most serious impact in any of the seven categories for all nine systems. The primary raw materials used for glass are plentiful minerals--sand and limestone. The use of these minerals is not a serious impact, so this index measure can be misleading. Numerous other examples of the misleading nature of the unweighted indices can be seen in Table 7.

Although the analysis of the comparative unweighted data is useful and informative, it is more desirable to establish a ranking of importance of the impacts. For example, energy use is a more important impact than the volume of water discharged or of raw materials used and this fact should be taken into account.

TABLE 7

UNWEIGHTED RESOURCE AND EFFLUENT INDICES FOR NINE BEVERAGE CONTAINER SYSTEMS

	19-RET	10-RET	5-RET	ABS	ALSTL	PCG	OWG	CSTL	ALUM
Raw Materials	33	55	122	34	72	235	268	60	21
Energy	32	43	86	134	76	125	133	105	167
Water	39	53	112	144	131	121	127	115	57
Industrial solid wastes	19	27	49	23	250	101	114	216	101
Atmospheric emissions	35	47	78	129	66	129	138	98	160
Waterborne wastes	26	31	55	55	240	45	46	231	172
Post-consumer solid wastes	40	66	159	149	19	205	226	18	18
Unweighted index	224	322	686	668	854	961	1,052	843	696

Source: Midwest Research Institute.

Information is not available to determine in absolute terms precisely what relative environmental damage is caused by each impact or by each effluent. However, grouping and ranking of the seven impact categories were carried out. These classifications are based on the knowledge and carefully considered judgment of environmental specialists at Midwest Research Institute. Guidance was also received from the open literature and environmental specialists employed elsewhere.

The seven impact categories were organized into three classifications according to the seriousness of their contribution to resource depletion and environmental damage as shown below. These impact types were ranked on the basis of their persistence, range of influence, and inherent environmental damage potential.

Most Serious	Intermediate	Least Serious
Energy use	Waterborne Wastes	Raw Material Use
	Atmospheric Emissions	Water Use
		Industrial Solid Wastes
		Post-consumer Solid Wastes

MRI has rated the most serious impact category as energy use. Much is being said and written at present concerning "the energy crisis" for the nation, especially in fossil fuels. There have been numerous instances of shortages of electric power. Locally, deficiencies in natural gas supplies and petroleum products are predicted for the immediate future. The long-term outlook is for much higher consumption rates of this resource which is mostly nonrenewable. The present and near-term future criticality of energy resources and seriousness of their depletion and short supply leads us to list energy use as the most significant impact category, at present.

Waterborne and airborne pollutants were deemed to be of intermediate seriousness for several reasons. First, pollutants are not easily controlled once they have left their source. They may have an effect on a large segment of the population far removed from the point of generation because of the migration of pollutants. This is not true of solid wastes, which have only a single point of influence that does not migrate. The water quality of underground aquifers and of large bodies of surface waters is not rejuvenated easily once these sources are polluted. For instance, it is estimated that it would take Lake Erie 200 years to recover completely, even if all sources of water pollution were cut off. On the other hand, air pollution may be cleared up in a much shorter time if the source of pollution is curtailed.

The least serious impacts are raw materials, water and solid wastes. Raw materials requirements for the nine systems are principally natural gas, petroleum and various minerals in abundant supply. As discussed in Chapter II, we have elected to include natural gas and petroleum in the energy category.

The other raw materials used are relatively abundant minerals for which hundreds of years of supply exist. Their use is not nearly as serious an impact as the use of energy. Thus, we assigned raw materials to the "least serious" classification.

The remaining resource is water which is not presently a scarce commodity in most parts of this country. Very little of the water used in the operations discussed here is actually removed from natural cycles, with the common process use being for cooling. Thus, the principal change in the process water is its temperature. Water volume was considered to be one of the least important impacts. (Water quality is discussed above.)

The two remaining categories are industrial solid wastes and post-consumer solid wastes. Industrial solid wastes are primarily mining wastes, although process and fuel combustion solid wastes were included. These wastes are usually generated in fairly remote areas, and are typically of mineral composition. Their disposal was considered to belong in the least serious category.

Post-consumer waste is generally discharged to municipal solid waste streams. The primary problem at present is the dwindling availability of land disposal sites, but otherwise the environmental effects are not as serious as that from air or water pollutants. Impacts from post-consumer disposal also include air pollution from incinerators, groundwater pollution from improperly operated landfills, aesthetic blight, and vector problems of open dumps. However, we have classified this as a "least serious" problem.

In order to weight the results of Table 7 to bring the desired perspective (that is, to show some impacts as less serious than others), it is necessary to translate our judgments into numerical "weights." We have somewhat arbitrarily selected the following set of numerical factors for the purpose of carrying out calculations.

Impact Classification	Weighting Factor
Least Serious	0.05
Intermediate	0.20
Most Serious	0.40

Our experience has shown us that the actual numbers selected for the weighting factors are not important, but the placement of the impact categories into the three classifications is important. That is, the ranking of the nine container systems will not substantially change if you consider solid waste to only be one-fortieth as important as water pollutants rather than one-eighth, as long as you assign it some value below that of water pollution. Thus, the major conclusions of this study depend very little on the weighting factors or values. (See discussion on p. 29.)

In order to construct the weighted index system, we made use of the unweighted indices in Table 7. Each unweighted index value was multiplied by the appropriate weighting factor to arrive at the weighted indices shown in Table 8. The composite index shown at the bottom of Table 8 represents our best estimate of the true, relative total environmental profile attributable to each container system.

E. Ranking of Systems

The weighted composite index values are summarized in Table 8. The 19-trip on-premise returnable glass container has the lowest overall impact index. In fact, its closest competitor is the 10-RET, which has 1.3 times the impact index value as 19-RET. Following the 10-RET is the 5-RET system, producing 2.7 times as much impact as 19-RET. The remaining six systems are all one-way systems, with aluminum having the highest index value. The ratio of ALUM to 19-RET impacts is 4.5.

F. Sensitivity

Table 9 contains a sensitivity analysis which aids in assessing how sensitive to error the rankings are. The table is in two sections which indicate how sensitive the ranking of a system is to data changes which would either reduce or increase the rank of the system by one.

For example, 10-RET is ranked in second place. To "improve" (reduce) its rank by one would be to move it from second to first. The first column of numbers shows that for this to occur, the raw materials total value used for 10-RET would have to be in error by -422 percent. Similarly, the energy value would have to be in error by -61 percent, and so on. The weighted composite would have to be in error by -26 percent. The lower set of numbers on the table shows that to move 10-RET to third place would require larger changes in the numbers. Raw materials total changes of 1,602 percent would cause this reversal in rank, or a 253 percent change in energy, and so on for the other impact categories. An overall change of 102 percent in the categories taken as whole would be required to move it from number two ranking to number three.

It is our judgment that the data are sufficiently accurate that an overall difference of 10 percent or more in the weighted composite is required to establish even a possibility of "real" distinction between two systems, and that an overall difference of between 10 and 20 percent represents only a possible marginal difference. For example, an overall change

TABLE 8

WEIGHTED RESOURCE AND ENVIRONMENTAL IMPACT INDICES FOR NINE BEVERAGE CONTAINER SYSTEMS

	Weight	19-RET	10-RET	5-RET	ABS	ALSTL	PCG	OWG	CSTL	ALUM
Raw materials	0.05	2	3	6	2	4	12	13	3	1
Energy	0.40	13	17	34	54	30	50	53	42	67
Water	0.05	2	3	6	7	7	6	6	6	3
Industrial solid wastes	0.05	1	1	2	1	13	5	6	11	5
Atmospheric emissions	0.20	7	9	20	26	13	26	28	20	32
Waterborne wastes	0.20	5	6	11	11	48	9	9	46	34
Post-consumer solid wastes	0.05	2	3	8	7	1	10	11	1	1
Weighted composite index	1.00	32	42	87	108	116	118	126	129	143
Rank of systems		1	2	3	4	5	6	7	8	9

Source: Midwest Research Institute.

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Table 9

SENSITIVITY ANALYSIS

		19-RET	10-RET	5-RET	ABS	ALSTL	PCG	OWG	CSTL	ALUM
PERCENT CHANGE TO REDUCE RATE BY 1										
NAME	UNITS									
INITIAL RANKINGS		1	2	3	4	5	6	7	8	9
DESIRED RANKINGS			1	2	3	4	5	6	7	8
RAW MATERIALS	POUNDS		-422	-721	-1209	-205	-20	-66	-58	-1407
ENERGY	MIL BTU		-66	-127	-36	-24	-4	-16	-3	-21
WATER	THOU GAL		-435	-781	-288	-113	-39	-141	-30	-507
INDUSTRIAL SOLID WASTES	CUBIC FT		-845	-1804	-1851	-58	-47	-158	-15	-246
ATM EMISSIONS	POUNDS		-123	-223	-80	-55	-8	-32	-8	-44
WATERBORNE WASTES	POUNDS		-186	-401	-190	-14	-26	-97	-3	-41
POST-CONSUMER SOL WAST	CUBIC FT		-350	-550	-278	-772	-23	-79	-197	-1653
WEIGHTED COMPOSITE INDEX			-26	-50	-18	-5	-1	-6	-0	-9
PERCENT CHANGE TO INCREASE RATE BY 1										
NAME	UNITS									
INITIAL RANKINGS		1	2	3	4	5	6	7	8	9
DESIRED RANKINGS		2	3	4	5	6	7	8	9	
RAW MATERIALS	POUNDS	694	1502	342	432	67	77	13	485	
ENERGY	MIL BTU	91	253	61	14	8	18	3	34	
WATER	THOU GAL	533	1652	371	103	37	150	28	253	
INDUSTRIAL SOLID WASTES	CUBIC FT	1204	3206	456	661	19	179	31	134	
ATM EMISSIONS	POUNDS	168	470	106	29	18	35	6	74	
WATERBORNE WASTES	POUNDS	224	710	141	68	5	102	19	31	
POST-CONSUMER SOL WAST	CUBIC FT	526	1332	262	100	251	88	16	1632	
WEIGHTED COMPOSITE INDEX		47	102	24	7	2	8	1	11	

of 5 percent is required to raise ALSTL to fourth place, and a 2 percent change to drop it to sixth place. Thus, we consider the system to be only marginally different from its nearest neighbors if actually different at all.

Considering the overall sensitivity values, only three systems are solidly positioned with respect to the others. The 19-RET, 10-RET and 5-RET systems have the lowest impact values. However, the remaining six systems are either in a tie with their nearest neighbors, or only marginally different. It is of interest to note that the three widely used conventional one-way containers, CSTL, OWG and ALUM, are all three considered to be in a "tie." Thus, one should not be singled out as being significantly "better" or "worse" than the other two.

The results are also sensitive to variation in weighting factors. In order for a rank to be immune to any changes in weighting factors, it is necessary for it to lead (or lag) in every category. However, a system such as 19-RET is highly insensitive to changes in the weighting factors because it leads in five of the seven categories. Our experience with using various sets of weighting factors shows that rankings are generally insensitive to moderate changes in weighting. However, complete reversals such as interchanging energy and industrial solid waste weightings would cause changes in rank of some systems. Examples of the insensitivity of the rankings are indicated in Table 10.

Table 10 shows four extreme options for weighting factors. For the first three options we have selected one of the three impact groups as being the only important one and have excluded the other two. Option four weights all impact categories equally. None of these options would be a reasonable alternative to the original ones selected, but they are used as an aid in the examination of the sensitivity of the results to weighting factors.

All four options included in Table 10 reveal shifts in the ranking. However, MRI emphasizes that the major conclusion of this study is that the three glass returnable systems (10-RET, 19-RET and 5-RET) are significantly lower in overall impact than the three conventional one-way systems now widely used (OWG, CSTL and ALUM). The remaining three hypothetical or little-used systems are intermediate. No matter which weighting option is chosen, the three returnable systems are not ranked 7, 8 or 9; and that the conventional one-way systems are not ranked 1, 2 or 3, except for option 3 which ranks only on the basis of the "least serious impacts." Thus, we conclude that no matter what values are chosen for the weighting factors, as long as the "least serious" category is weighted less than the others, the returnable systems rank better than the conventional one-way systems. The remaining three systems (ABS, ALSTL and PCG) change their positions somewhat depending on the option chosen. Depending on the weighting factors, these

TABLE 10

SENSITIVITY OF RANK TO WEIGHTING FACTORS

Assignment of Weighting Factors for Selected Extreme Options

Impact Group[a/]	Original Calculation	Option 1	Option 2	Option 3	Option 4
Most serious	0.40	1.0	0.0	0.0	1.0
Intermediate	0.20	0.0	1.0	0.0	1.0
Least serious	0.05	0.0	0.0	1.0	1.0

Rank of Systems

Container System	Original Calculation	Option 1	Option 2	Option 3	Option 4
19-RET	1	1	1	1	1
10-RET	2	2	2	3	2
5-RET	3	4	3	6	3
ABS	4	8	6	4	4
ALSTL	5	3	7	7	7
PCG	6	6	4	8	8
OWG	7	7	5	9	9
CSTL	8	5	8	5	6
ALUM	9	9	9	2	5

a/ The weighting factors listed are applied to each of the impact categories in the impact group.

Source: Midwest Research Institute.

three systems may overlap into either the returnable group or the conventional one-way group. However, the particular position of the "little-used" three container systems is somewhat sensitive to the weighting factors.

G. Energy Considerations

In the closing months of 1973, a dramatic and precipitous political situation triggered a national "energy crisis" that had been evolving and forthcoming under other circumstances. This crisis was caused in part by a sudden reduction in volume of worldwide petroleum reserves which were usable by the U.S. Changes such as this can cause alterations in the values selected for weighting factors. In fact, in times of emergency, option 1 on Table 10 may become operative, where energy is the only impact of importance.

To examine our results in terms of energy alone, Tables 11 and 12 were prepared. These tables provide details not only on total energy requirements for each system, but on the sources of energy. It is our point of view that in the long term, total energy is the important parameter to use. The various forms of energy may be interchangeable if long-term planning is utilized, and no great advantage can be presently ascertained with any degree of certainty by using coal as an energy source rather than oil. However, for the short term, oil and natural gas are in quite short supply and industrial use of these fuels competes with home heating and other uses closely coupled to the quality of life. Thus, in the short term, we believe use of hydrocarbons by industry is generally considered to be a less desirable form of energy use than coal or wood (although the associated environmental effluents may be lower in the case of the use of hydrocarbons).

Data found in Tables 11 and 12 show that for the conventional systems, the three glass returnable configurations are lower in total energy use, and the 19-RET and 10-RET presently utilize less total hydrocarbon fuels than do the conventional one-way systems. However, for the conventional one-way systems, CSTL utilizes slightly less hydrocarbons than 5-RET, but only 57 percent as much hydrocarbon fuel as OWG, and only 52 percent as much as ALUM. Thus, CSTL appears to require less of those important fuel resources, although it utilizes 2.2 times more coal than OWG.

For the nonconventional beer systems (ALSTL, ABS and PCG) we see that ALSTL compares well with 10-RET in hydrocarbon usage, but utilizes 5.9 times as much coal, and 1.7 times as much total energy. The ABS container is ranked eighth in total energy use and ninth in natural gas use. Thus, ABS does not fare very well in the energy analysis. This hydrocarbon usage is in part related to the large amounts of natural gas and petroleum used as a material resource (0.47×10^9 joules petroleum and 5.1×10^9 joules natural gas) for which alternate materials do not presently exist. However, some of this energy could be recovered by incinerating solid waste streams and recovering the energy. It should be noted that plastic formulations other than the ore used here by MRI may result in lower energy values than those used here.

TABLE 11

ENERGY REQUIREMENTS BY FUEL SOURCE FOR CONTAINER SYSTEMS DELIVERING 1,000 LITERS (OR 1,000 GALLONS)

10^9 JOULES (MILLION BTU)

	19-RET	10-RET	5-RET	ABS[a/]	ALSTC[a/]	POC[a/]	OMG	CSTC	ALUM
Petroleum	1.41 (5.06)	1.74 (6.24)	3.13 (11.23)	3.21 (11.51)	1.39 (4.98)	3.52 (12.65)	3.69 (13.23)	2.66 (9.57)	4.69 (16.83)
Natural Gas	2.11 (7.60)	2.99 (10.72)	5.41 (19.40)	12.51 (44.86)	3.56 (12.77)	10.34 (37.10)	11.23 (40.27)	5.80 (20.79)	11.47 (41.15)
Hydrocarbon Subtotal	3.52 (12.66)	4.73 (16.96)	8.54 (30.63)	15.72 (56.37)	4.95 (17.75)	13.86 (49.75)	14.92 (53.50)	8.46 (30.36)	16.16 (57.98)
Coal	0.80 (2.88)	1.10 (3.94)	2.21 (7.94)	2.92 (10.50)	6.45 (23.15)	3.24 (11.63)	3.42 (12.29)	7.41 (26.58)	8.97 (32.17)
Wood Fiber	0.49 (1.78)	0.76 (2.73)	2.24 (8.03)	1.69 (6.06)	0.08 (0.29)	1.80 (6.48)	1.79 (6.44)	0.11 (0.39)	0.19 (0.69)
Total Energy	4.81 (17.32)	6.59 (23.63)	12.99 (46.60)	20.33 (72.93)	11.48 (41.19)	18.90 (67.86)	20.13 (72.23)	15.98 (57.33)	25.32 (90.84)

a/ These are hypothetical or little used as beer containers.

TABLE 12

RANKING OF SYSTEMS FOR ENERGY REQUIREMENTS FOR EACH FUEL SOURCE

	19-RET	10-RET	5-RET	ABS[a/]	ALSTL[a/]	PCG[a/]	OWG	CSTL	ALUM
Petroleum	2	3	5	6	1	7	8	4	9
Natural Gas	1	2	4	9	3	6	7	5	8
Hydrocarbon Subtotal	1	2	5	8	3	6	7	4	9
Coal	1	2	3	4	7	5	6	8	9
Wood Fiber	4	5	9	6	1	8	7	2	3
Total Energy	1	2	4	8	3	6	7	5	9

a/ These are hypothetical or little used as beer containers.

The energy analysis, then, does not change the conclusions previously reached. The returnable systems have the lowest index values. They require less total energy and generally require less valuable hydrocarbon fuels than do the one-way systems.

H. Discussion of Systems

1. 19-RET, 10-RET and 5-RET Systems: These systems utilize a 12-ounce glass bottle weighing 277 grams which on the average makes 19, 10 or 5 trips before being discarded. Each bottle is capped with a 1.8 gram steel closure. Another major distinction in these systems is that the 19-RET system is a container which is used "on-premise." That is, the beverage is consumed at a business establishment. The 10-RET and 5-RET are "off-premise" type containers and are taken off-premise for consumption. The off-premise container requires a six-pack carrier, while 19-RET does not require a six-pack carrier. The 10-RET is assumed to achieve three trips for its six-pack container, as well as the corrugated container that carries the filled six-packs. But for 5-RET, we have assumed only one trip for the paper packaging.

The assumption of using one-way system packaging for 5-RET is valid for the situation as it existed in Oregon in 1973. At that time the breweries were receiving their off-premise returnable bottles in any package "that was handy" at the retail store from which the bottles were returned. Packages that belonged to competitors were discarded at the brewery. However, we assume that given sufficient time and planning, the situation could improve to the point where more careful sorting would occur and some trippage could occur for the boxes and six-pack carriers.

The environmental advantage of the returnable systems lies in the fact that much less material is needed for bottle construction to deliver a unit of beverage than for a corresponding one-way container. In fact, a single returnable container will deliver 19, 10 or 5 units of beverage compared to only one for a one-way bottle. This is partially offset by the fact that returnable bottles are heavier and require more raw materials per bottle than one-ways, and they also require transportation for the return trip, and extensive washing.

A review of Tables 5 and 6 shows that 19-RET leads all other systems by an impressive overall margin, and it leads in five of the seven categories. The two categories which it does not lead are raw materials (second place) and post-consumer solid wastes (fourth place). In the three most important categories--energy, atmospheric emissions and waterborne wastes--19-RET leads by a sizable margin over nonreturnable containers. It requires only 30 percent as much energy and produces 35 percent as much

air pollution as CSTL, the nearest conventional one-way container in those groups. It produces only 56 percent as much water pollution as OWG. The 10-RET and 5-RET systems lead the conventional one-way systems also by a sizable margin in energy and air pollution. However, 5-RET produces 1.2 times as much water pollution as OWG, although producing less impact than OWG in the other six categories.

Thus, we judge the 19-RET, 10-RET and 5-RET systems to be the systems which produce the least overall environmental damage. Table 8 confirms this, showing that the weighted indices for these three systems are lower than for any other systems.

Some additional points of interest can be found in the detailed data in Volume II. The detailed profile of 5-RET (Volume II, Table 9) shows that 53 percent of the weighted impacts are related to the paper packaging system, while the glass container system accounts for 24 percent, filling operations are 11 percent and three other operations form the remainder. Thus, the packaging assumptions are quite important. We performed calculations for a 5-RET system with various trips for the packaging. We found if two trips per package are used instead of one trip, the impact index of 5-RET is lowered from 87 to 68. At three trips per package, the index for 5-RET is 50, moving it much closer to 10-RET. Thus, the assumptions concerning the paper packaging for 5-RET affect its relative position to the other containers.

2. ABS: The ABS system utilizes a 35-gram ABS plastic bottle in a one-way configuration. This is a hypothetical bottle, and to our knowledge no company is planning to market this particular bottle. However, the impacts of this bottle are judged to be similar to impacts which are produced by proprietary nitrile based polymers presently being test marketed as beverage containers. Therefore, even though this system is a hypothetical construction, it approximates plastic containers projected for future use.

The most serious impact of the ABS profile is energy use. The ABS system ranks eighth in energy, although it ranks fifth overall. An important aspect of this energy value is that it contains the energy equivalent of the hydrocarbon feedstock, although that energy is not utilized in this system. The energy of the material resource accounts for 29 percent of the total ABS energy. It is interesting to notice that even though this plastic uses a fuel for a material feedstock, there is one other system--ALUM--that leads to a greater utilization of the nation's energy consumption than the other systems. ABS uses only 8 percent more energy than OWG. However, as a one-way system it still requires 4.2 times as much energy as the first place 19-RET system.

It is interesting to notice that if the hydrocarbon feedstock for ABS is counted as kilograms of raw material rather than joules of energy,

the ABS system then ranks fifth in energy (rather than eighth), and virtually ties with the 5-RET system with an overall weighted index of 88. Two important impacts for ABS are air pollution and water pollution, for which the ABS ranks sixth for both. The detailed calculations in Volume II of this report show that the air pollutant total for ABS is 23 percent hydrocarbon emissions. The average for all systems is 18 percent. In most areas of the country, hydrocarbon emissions are considered to be less important than most other emissions. In addition, an indeterminate but large fraction of the hydrocarbon emissions listed for ABS is methane, usually not considered to be a pollutant. Thus, the air pollution for ABS would be judged as slightly less serious than for other systems, but this difference would not affect the ranking of the ABS system.

The water pollution from the ABS system has several important components. The largest is that related to paper packaging manufacturing which produces BOD and suspended solids discharges which account for 46 percent by weight of the total system water pollution. Another 7 percent is generated off-site from the major manufacturing and processing sites. This is oil field brine (dissolved solids), a serious fresh water pollutant that can result from improperly disposed brine associated with oil and gas production. The rest of the water pollution is generated on site at the container manufacturing and processing plants.

3. ALSTL: The sixth place ALSTL system utilizes the nearly extinct one-way all steel can. The system is characterized by low energy requirements, air pollution and post-consumer solid waste and high water pollution, industrial solid wastes and water use. It leads six other systems in the first three categories mentioned, but is eighth or ninth in the three others. The energy consumption and air pollution discharges of the steel industry are well known to be serious environmental problems, but this is in part because steel mills are quite large and severely impact the environment of local areas. However, these impacts, when allocated to unit beverage containers, are low compared to other container systems. They are second only to 19-RET and 10-RET.

The ALSTL system produces massive amounts of industrial solid waste and water pollution, both associated with iron ore mining. Perhaps the most significant feature of the steel profile is that the massive water pollution problem is caused by a single mine which discharges taconite tailings in the form of suspended solids into Lake Superior. This problem is so immense, that if these wastes were impounded and disposed of as solid waste ALSTL would move from sixth place to third place, and would be the lowest of all systems in total water pollutants. Thus, this one change would have a significant effect on the rank of ALSTL. One other interesting aspect of the system is that 28 percent by weight of the water pollution (excluding taconite tailings) is waterborne acid and metal ion associated with coal production.

Thus, this water pollution occurs at the mine site, not at a manufacturing or processing site. However, 49 percent of the air pollution for the entire system does occur at the steel mill.

4. PCG and OWG: The systems in sixth and seventh place are both basically glass systems. The OWG system uses a 186-gram glass bottle with a steel crown. The PCG is a 159-gram glass bottle with a 2-gram plastic coat and a steel crown. The plastic coat accounts for only 3 percent of the weighted PCG impacts, so the PCG profile is quite similar to the OWG profile and will not be discussed separately.

The OWG system ranks ninth (last place) in both the raw materials and post-consumer solid waste categories, and PCG ranks eighth in those two categories. The high raw material use is because glass containers require many more kilograms of material for their manufacture than the other systems. This is shown by the fact that OWG is by far the heaviest one-way container, outweighing next place ALSTL (54 grams) by a factor of 3.4. The large post-consumer waste values are caused by a combination of the high weight of the container coupled with relatively low density of glass. This combination causes a relatively large volume of landfill space for each container. However, these two categories are in the "least serious" impact groups and so are not the greatest environmental impacts of glass.

The more significant impact for glass is the fact that OWG ranks seventh in energy and eighth in air pollution (PCG ranks seventh in air pollution and sixth in energy). The large energy requirement is mainly concentrated in two operations (Volume II, Table 8): glass manufacture accounts for 58 percent of the OWG system energy total and paper packaging with 25 percent. Thus, these two operations account for 83 percent of the energy. These two operations also account for most of the air pollution, with glass manufacture accounting for 41 percent (mostly nitrogen oxides and hydrocarbons), and paper packaging accounting for 29 percent (mostly particulates and sulfur oxides).

Glass fares better in the remaining impacts, with OWG ranking seventh in both water and industrial solid waste (PCG ranks fifth in industrial wastes, sixth in water). But in water pollution, OWG and PCG are nearly tied for third place. Seventy-two percent of this is attributed to packaging. Glass manufacturing plants generally do not have serious water pollution problems, and this is reflected in the favorable position of OWG in the water pollution category.

5. CSTL: The eighth place system is the conventional bimetal can consisting of a steel body and bottom with an aluminum ring pull top. The weight of the steel used per can is 43 grams, while the lid requires only 5.4 grams. However, even though the lid comprises only 11 percent by weight

of the can metal, its manufacture accounts for 32 percent of the weighted impacts (see Volume II). Thus, the rank of CSTL as opposed to the higher position of ALSTL is a result of the aluminum closure's environmental impacts.

The most significant impact for CSTL is the water pollution associated with iron ore mining (as discussed for ALSTL), which accounts for 73 percent of the water pollution for this system. Also of importance is water pollution associated with the aluminum top. This accounts for 23 percent of the water pollution total of CSTL. Only about 2 percent of the system water pollution actually occurs on-site at steel mills, long cited for their water pollution problems. The system also ranks eighth in industrial solid wastes, which are primarily iron ore mining wastes.

Partially offsetting CSTL's showing in the two categories discussed, CSTL ranks fifth in all other categories except post-consumer solid wastes, where it ranks second. As discussed for the ALSTL system, the removal of taconite tailings would have influence on the rank of CSTL. However, because of the use of the aluminum top, CSTL only moves to seventh place if taconite is removed.

Post-consumer waste disposal is small. (In fact, all of the metal can systems have quite low post-consumer disposal profiles.) This is the result of two factors. First, can systems require less packaging for carriers because they do not require "cushioning" to the extent that glass containers do; and cans utilize the plastic ring six-pack carriers which occupy only about one-tenth as much volume as paper carriers. Recently the use of adhesives has come into play as well, to bind six packs. The second factor is that metal cans are more dense than other materials and require considerably less landfill space. In fact, a steel can occupies only 8 percent of compacted volume of a one-way glass container.

6. ALUM: The aluminum can for the ALUM system is a 20-gram all aluminum can with a ring pull top. This system has the highest weighted impacts on the environment of the nine systems studied. It produces 4.5 times the weighted impacts of 19-RET, but only 1.1 times as much as its nearest neighbor. It results in greater quantities (and thus greater impacts) in two of the three most important categories--energy and air pollution. In addition, there is a significant gap between ALUM and the eighth ranked system for each of these two impacts.

Perhaps the most serious impact for ALUM is energy. ALUM requires 1.2 times as much energy as does ABS, the system ranked seventh in energy, and 5.2 times as much as 19-RET. The massive electric energy requirements with their attendant water and air pollution have long been cited as environmental factors in the aluminum industry. Industry spokesmen often counter that their high usage of hydropower should be the determinant factor. However,

MRI's calculations have been based on the point of view that national average electricity fuel data should apply in all cases because of the large-scale inter-regional nature of many electric power grids. In addition, it would seem contrary to good environmental reasoning to give a selected industry rewards for using large amounts of hydropower, thus diverting that power from the use of others. Nevertheless, we have carried out alternative calculations using Aluminum Association data for hydropower usage and assigned no environmental impacts to its use, thus, effectively reducing the electric energy requirements for aluminum. The results of that calculation show a reduction in the ALUM index, making it comparable with other one-way container systems. Thus, there is improvement in the ALUM position.

The other major impact is atmospheric emissions. ALUM produces 1.2 times as much as eighth-ranked OWG, and 4.6 times as much as 19-RET. This air pollution is primarily from electric power generation. This is reflected by the fact that sulfur oxides and particulates combined form 49 percent of the air pollution, as compared to 42 percent for the all systems average. Thus, the air pollution shows a slightly higher composite concentration of these two air pollutants. (If a hydropower source of electrical energy is used the air emission values would decline also to the extent fossil fuel requirements decline.)

In the least serious impact categories, ALUM ranks much higher. It is sixth in industrial solid wastes, third in water use, and first in raw material use and post-consumer disposal. Its high standing in the raw materials category is caused by the fact that nearly 90 percent of the bauxite is imported and thus is not counted as a raw material in this study. Its high ranking in post-consumer solid waste is because the aluminum can uses very little material, and because that material is dense and occupies relatively little landfill space. The aluminum can weight of only 20 grams is by far the lightest container.

ALUM ranks seventh in the important category of water pollution. Eighty-seven percent of this is "red muds" being discharged into the Mississippi River by two plants. Plans are under way to begin impounding these pollutants in the near future. When this occurs, some improvement will result in the profile of ALUM, similar to the improvement which will be experienced in the steel profiles when the taconite tailings are no longer discharged.

As discussed in Chapter III, p. 29, the placement of ALUM in last place should not be considered definite or final at this time. Rapid changes are taking place in all industries and alterations in their resource and environmental profiles occur daily. The primary conclusion reached in this study is that returnable (glass) containers are better, from a resource and environmental point of view than any widely used one-way container

today. However, this study shows that the relative ranking of the three widely used one-way containers--OWG, CSTL and ALUM to each other--is difficult to carry out with validity because the differences between the overall indices are small, and because conditions are rapidly changing.

CHAPTER IV

REUSE AND RECYCLING

One of the possible means of achieving environmental improvement is by employing reuse and recycle options. The reason why these options are of potential benefit to the environment is that reuse and recycle avoids the virgin materials manufacturing operations which produce impact on the environment. However, the bypassing of these manufacturing operations must be weighed against the new operations of product reuse and of secondary materials recovery, processing and transportation.

A. Returnable Bottles

Figure 3 summarizes calculations showing the environmental effects of product reuse. Dramatic improvements occur in returnable bottle systems. Three such systems are plotted so that the environmental improvement at various trip rates is shown. The three systems are on-premise glass bottles with three-trip paper packaging, off-premise glass bottles with one-trip paper packaging, and a hypothetical on-premise ABS returnable bottle with three-trip paper packaging.

The initial part of the three curves (low trippage) shows a very steep downward slope, indicating a considerable lowering of the environmental impact at even quite low trip rates. In fact, at only two trips, the on-premise bottles produce lower impact than any one-way container. At three trips, the off-premise system surpasses any one-way system.

The rapid leveling off of the returnable curves implies that a lower limit exists for returnable systems. In fact, this lower limit is the returnable processing impacts which are 21 for the on-premise bottle and 58 for the off-premise bottle. The implication is that for returnable systems capable of high trip rates, the impacts of manufacturing the bottle are negligible. For returnable bottles, then, impacts may be minimized by using a quite durable bottle capable of high trip rates. This is counter to current trends of using lighter bottles where possible. The reason for this is that market factors increasing economics tend to favor the lighter bottles, even though environmental considerations may favor a heavier bottle reused many times.

An interesting calculation can be made concerning one type of possible marketing change. Most beverage markets are served by a broad array

of returnable and one-way containers. However, legislation or other changes in marketing conditions can bring about a change in the mix of container types used. For example, laws banning or restricting in some way the availability of one-way containers can convert a marketing area to use only returnable systems.

The change to a "returnable only" situation will generally produce new aspects of these systems. We have previously pointed out that one problem the beer industry has experienced in Oregon as a result of the "bottle law" is in each company securing their own packaging back with the returnable bottles, thus effectively reducing the trip rate of the packaging. Another question which arises is if customers accustomed to throwing away convenience packaging will return the bottles for the deposit or throw them away, thus creating a "one-trip" situation for the returnable bottle system.

Figure 3 shows that the heavy returnable bottle discarded after one trip has a much higher impact index that most one-way systems. The question then arises as to what fraction of the market can be served by "one-trip returnable" (1-RET) before it is environmentally desirable to return to one-way container systems.

To answer this question, we have looked at three market composites and calculated the percent of returnable bottles which must be discarded after one trip before the market composite environmental index rises to 126, the value for the lowest commonly available one-way system (OWG). Those three composites should cover a realistic range which would be experienced in United States regional markets. The first market composite assumes that the market is partially 19-RET, with the remainder of the market being 1-RET (one-trip off-premise). The second composite is a mix of off-premise 5-RET and 1-RET. The third mix assumes that the market is 20 percent 19-RET, with the remainder being shared between 5-RET and 1-RET.

The results of the calculation show that the market share for 1-RET must be 55 percent, 33 percent and 42 percent, respectively. Thus, in the most pessimistic case of having only 5-RET and 1-RET systems present, consumers must discard 33 percent of the returnable bottles after one trip before a currently available one-way system is more "acceptable." But if higher trip rates and more favorable conditions exist, about 50 percent of the returnables must be discarded after one trip before a conventional one-way system is more environmentally "acceptable."

B. Recycling

The effect of recycling on the composite weighted index is depicted in Figure 4. This figure shows that impressive environmental gains are made by recycling materials from solid waste streams. This is most evident for

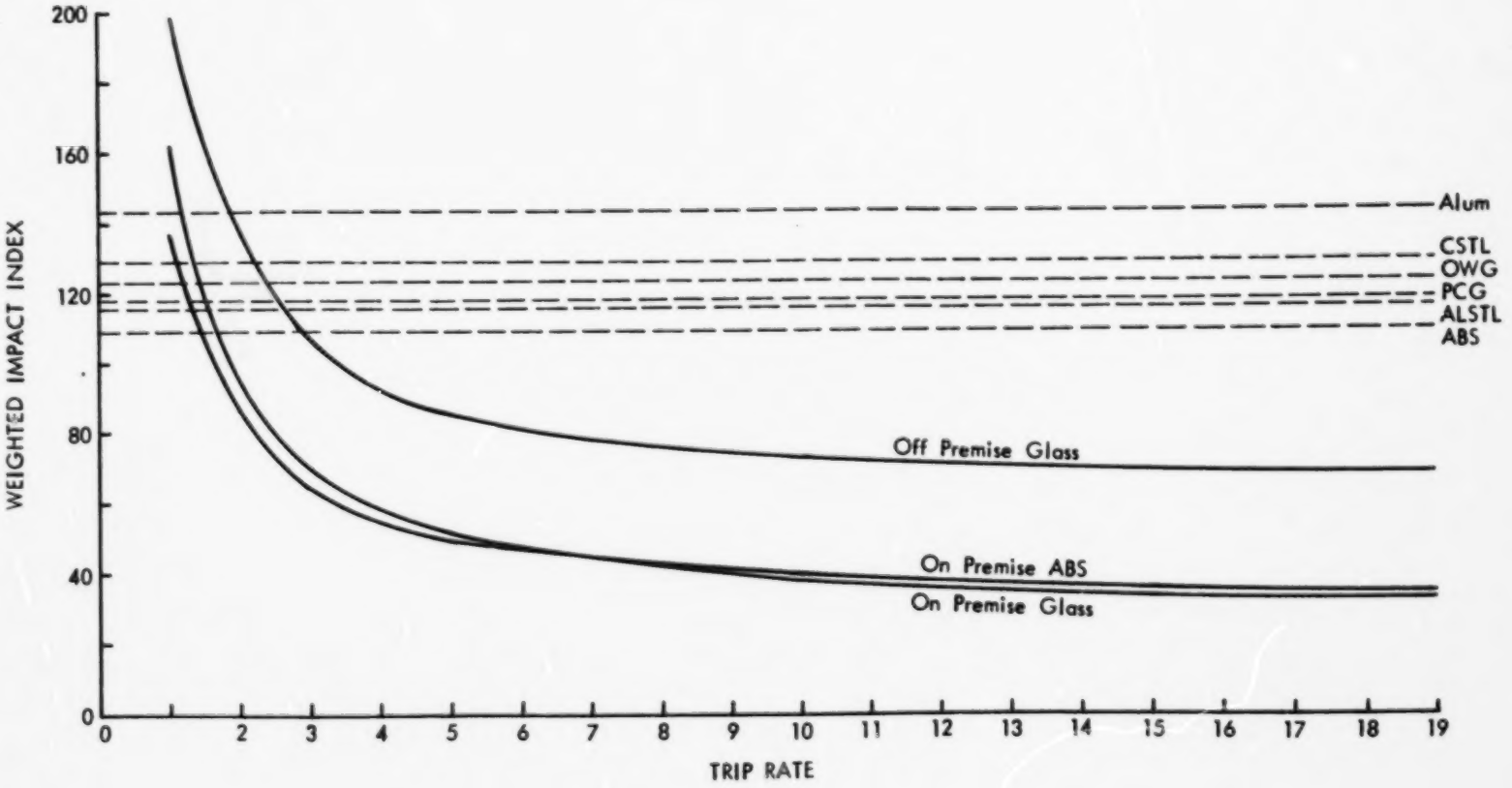

Figure 3 - The Effect of Trip Rate on Weighted Impact Indices

ALUM, where the index of 143 is reduced to 26 for 100 percent recycling, an 82 percent reduction. Improvements in the other systems are significant, but not as great. For steel, the improvement is 64 percent; for ABS, 60 percent; and for glass, 6 percent. These values are based on the fact that recycling not only bypasses many of the conventional manufacturing processes, but also reduces post-consumer solid waste by significant amounts.

One complicating factor of the recycled materials profiles is the assignment of energy to recover containers. If containers are recovered by mechanical means from a solid waste stream, the recovery energy is not large compared to the total recycled system energy requirements (i.e., if the whole waste stream is processed for recovery). However, recovering cans through a voluntary can reclamation center presents a different picture. In one circumstance, cans are transported by auto to a supermarket collection center, or other location to which a trip could be considered a necessity. The purpose of a trip such as this is primarily to buy food, or medicine, or other goods necessary to life so that the cans ride "piggy back." No energy of transportation needs to be assigned in this case. However, if a specific auto trip is undertaken to take cans to a reclamation center, then impacts of the entire round trip should be charged to the cans.

We have calculated the impacts of carrying aluminum cans to a voluntary center by auto. At 1 gallon of gasoline consumed per 100 cans, the change in the 100 percent recycled index of aluminum is to increase 38 percent, an increase from an index value of 26 to 41. This represents a round-trip by car to a collection center only 10 to 15 miles from home with about four cases of cans in the trunk. However, this is still an index value better than 5-RET or any other one-way system. In fact, a gasoline consumption of at least 5 gallons per 100 cans is required before the 100 percent recycled aluminum index becomes equal to OWG, the "best" conventional one-way system. Thus, even though long travel with empty aluminum cans is a negative environmental factor, it is usually better than any currently used one-way system, as long as "one-way" packaging is used in the first instance.

Looking at 100 percent recycling values is only of academic interest because such recovery rates from solid waste streams are not possible on a regional or national basis. Much of the potentially recoverable materials are discarded into waste streams in such low concentrations that to recover it economically is not possible. It is probable that only where quite large volumes of waste are processed, can recovery of materials be practiced economically. In addition, the discarded materials,when recovered, are sometimes contaminated so that reuse is difficult.

A possible recycling rate for various materials is difficult to determine, but for purposes of comparison we used a 50 percent recycling rate compared to returnable options. Figure 4 shows that near 50 percent

recycling both aluminum and glass have index values that are not as low as using a returnable system. At 50 percent recycled plastic, the ABS bottle is nearly equivalent to 50 percent of steel recycled, and both are slightly better than 5-RET. However, none of the 50 percent recycled containers have index values lower than either 10-RET or 19-RET glass.

In view of the fact that even 50 percent recycling from post-consumer waste is not likely on a regional or national basis in the near future, we conclude that recycling of aluminum or glass substantially improves the profile but does not lead to an environmental profile with a lower index value than that of other readily available reusable container systems. In fact, the 5-RET system which we consider as a "lowest limit" for returnable systems has a lower overall impact than glass and aluminum recycle systems, at 50 percent recycling rates.

On the other hand, two container systems not now widely used--ABS and ALSTL--may show more environmental improvement resulting from recycle options. The ABS and ALSTL one-way which have higher impacts than 5-RET can become equivalent to it at less than 40 percent recycling. But this high a recycling rate seems improbable in the near term for either. On the other hand, Figure 3 shows that a 2- to 5-trip ABS returnable would do as well, so it would seem that a logical choice is to look to ABS as a returnable system if environmental improvement is desired. Or even better, an ABS returnable bottle made from recycled polymer could conceivably be used.

One environmental problem not quantified here is littering but perhaps it is reasonable to assume that a one-way container of any type would tend to be littered more than a returnable system. To alleviate the litter problem associated with one-way containers, perhaps a "required" return could be instituted (e.g., a deposit). This would have the dual advantage of reducing litter and providing containers for recycling purposes.

Basing calculations on experience gained from recovery rates experienced with bottles, we can estimate the environmental effects of a deposit on cans. If we assume that a deposit on cans will stimulate can recovery similar to that experienced for 5- or 10-trip bottles, the percent recovery for cans is 80 percent and 90 percent, respectively. An examination of Figure 4 shows that the impact index for both all steel and aluminum cans for the range of 80 to 90 percent recycling falls between 5-RET and 10-RET. Thus, at those high recycling rates, the impacts for cans become comparable to conventional off-premise returnable glass bottle systems.

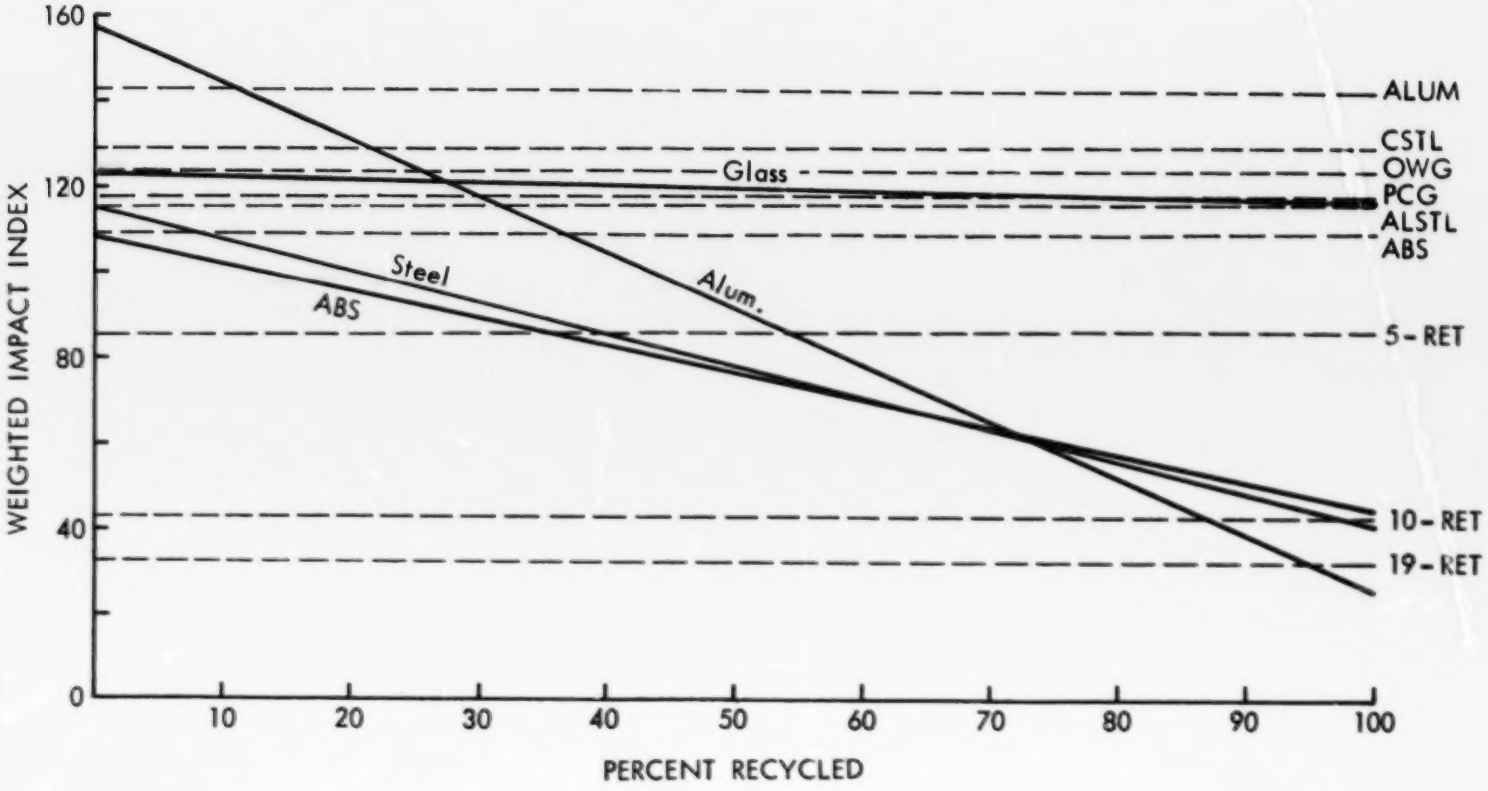

Figure 4 - The Effect of Recycle Rate on Weighted Impact Index